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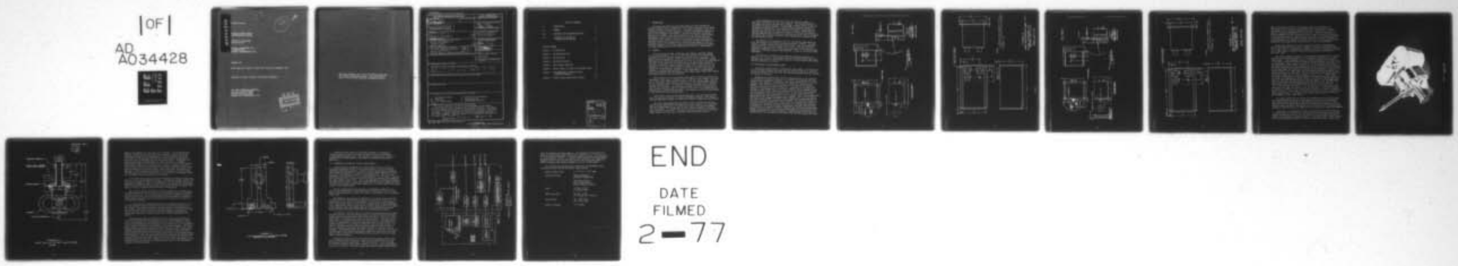

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SATELLITE DENSITY GAUGE
INSTRUMENTATION PROGRAM

Theodore E. Ciesielski
John Dulchinos

EPSILON LABORATORIES, INC.
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BEDFORD, MASSACHUSETTS 01730

OCTOBER 1976

Final Report for Period 15 March 1974 through 30 September 1976

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AIR FORCE GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
UNDITED STATES AIR FORCE
HANSCOM AFB, MASSACHUSETTS 01731

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6. Electrometer amplifier

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The report describes the design and development of two density measuring systems to be included in an Air Force satellite. The sensor is a cold cathode gauge used for the measurement of density at satellite altitudes. A second experiment will serve to provide data relating to the vehicle attitude. Both instruments utilize electromer amplifiers in the range of 10^{-4} A to 10^{-9} A.

0.0001 A to 10 to the minus 9th power A.

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I. INTRODUCTION

The report describes work performed under Air Force Contract No. F19628-74-C-0156 for the development of two satellite-borne density gauge systems by Epsilon Laboratories, Inc. The effort represents a part of a continuing program of upper atmospheric density measurements conducted by the Air Force Geophysics Laboratory. The program includes the design, fabrication, assembly, test and calibration of two density gauge systems designated the cold cathode gauge (CCG) system and the particle flux accumulator (PFA) system. As part of the program Epsilon Laboratories was also required to investigate the feasibility of adapting commercially available cold cathode gauges and/or custom designed gauges for use in the above systems. To this end, Epsilon Laboratories selected the Model 529 gauge manufactured by Cabot Corporation of Billerica, Massachusetts.

II. GENERAL

The two density systems incorporate cold cathode ionization gauges as the sensing element. One of the systems,designated the cold cathode experiment serves to measure atmospheric density and its variation. This data is used to upgrade and refine existing Air Force atmospheric models. Knowledge gained from this measurement will also be of use in the investigation and study of the mechanism and energy sources by which these variations (diurnal, semi-annual, annual, geophysical and solar related effects) are propagated. The cold cathode sensor is opened in the satellite orbit and exposed to the atmosphere. Atmospheric gas flows into the sensor cavity creating an internal gauge pressure. Direct measurement of atmospheric density is obtained from the response of the gauge output signal which varies with ambient density and vehicle motion.

The principle of the cold cathode gauge derives from the so-called Penning gauge. This class of sensors does not require a hot filament as do some other conventional type ionization gauges. The cold cathode gauge consists of two electrodes separated by a cylindrical or ring shaped anode located in an axial magnetic field. A potential of several thousand volts is applied between the electrodes. The electrons produced in the gas discharge oscillate in spiral paths between the cathodes, producing an ion current that is proportional to internal gas pressure. Such gauges are used for measurements in the 10^{-4}-10^{-12} Torr pressure region.

Gauge output signal is directly proportional to the measured pressure which in turn can be related to ambient atmospheric density. The shape of the spin modulated response is a function of ambient temperature and density.

The other system designated the particle flux accumulator will also perform direct measurements of atmospheric neutral density. Data generated from this measurement will be used to test, improve and simplify current Air Force models. The accumulator will be directly exposed to the atmosphere during satellite orbit. The particle flux into and out of the accumulator results in a build-up of pressure inside the sensing volume.

This accumulation of particles within the detector volume is partially ionized and the ion signal measured. The measured positive ion signal can then be related to the chamber pressure which in turn can be related to ambient density. Another mode of operation consists of extending and retracting a plane parallel baffle which interrupts the transport of particles into the accumulator creating a signal dropout. The resulting decrease in gauge ion current as a function of baffle extension combined with the geometric configuration can be used to determine the aspect angle between the particle flux accumulator's sensitive axis and the velocity vector.

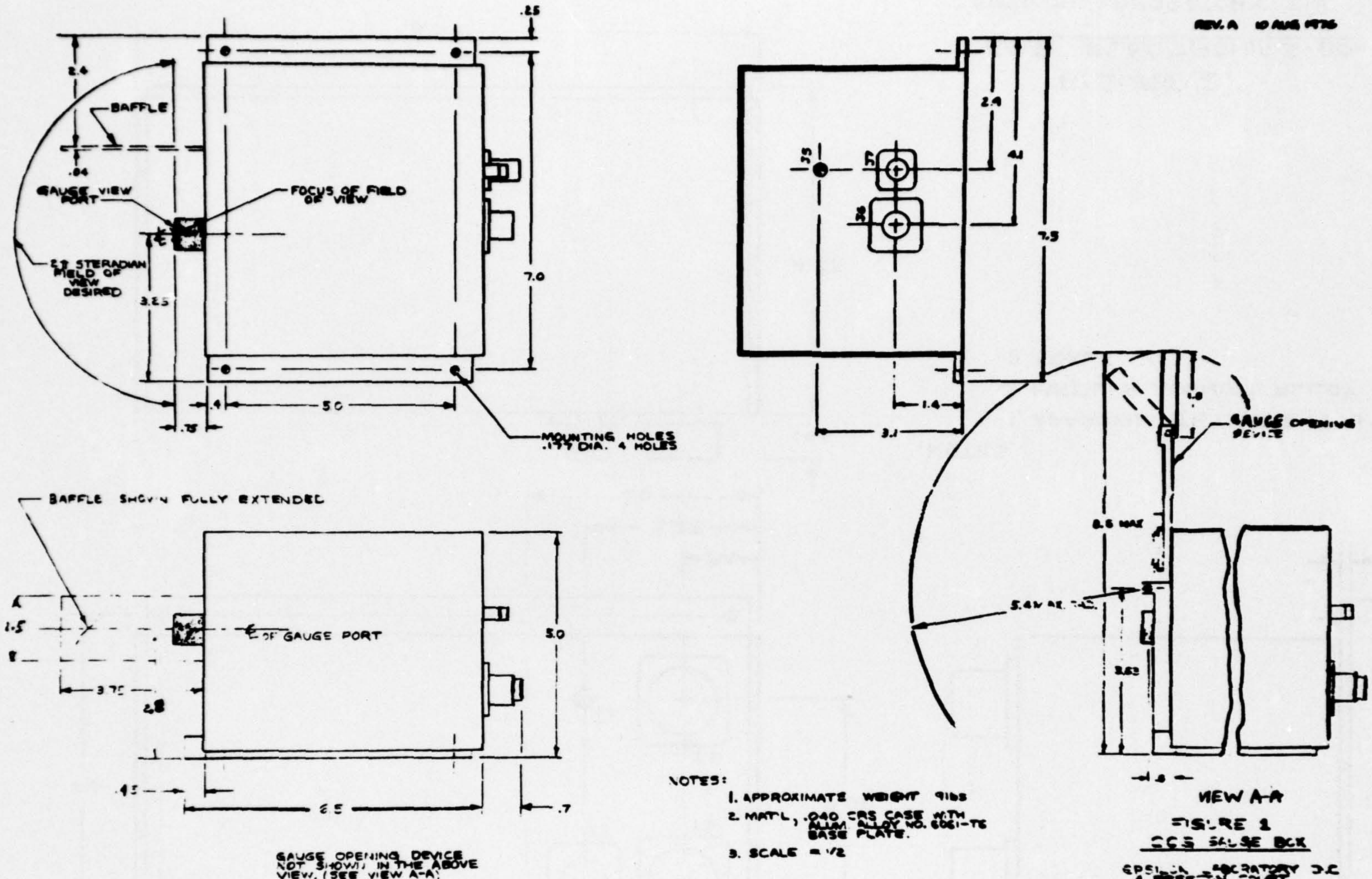
The particle flux accumulator and the cold cathode experiments employ two different cold cathode ionization gauges as sensors. An AFGL ionization gauge of Kovar and glass construction, that was successfully flown on the OV3-6 Air Force satellite, is used in the particle flux accumulator experiment and a Cabot Corporation Model 529 Ionization Gauge (employing a modified internal configuration) is used in the cold cathode experiment.

Each system is contained in two physical packages, depicted in Figures 1, 2, 3 and 4. One package houses the ionization gauge and high voltage module and the other package contains the electrometer power supply and other electronic circuitry.

III. DISCUSSION OF DEVELOPMENT EFFORTS

During the initial period of the design, which began in the early part of 1974, several meetings were held with the Contract Monitor in order to review the design so that technical and interface problems could be resolved as promptly as possible.

Modifications incorporated into the instrumentation at the beginning of the program included the addition of a baffle arm requirement for the particle flux accumulator experiment. The baffle operation was to be controlled by two signals, a "baffle extend" command and "baffle return" command. Also the instrument would include a D-C monitor voltage which would be proportional to baffle extension. Subsequent to the above discussions it was decided that in the event a baffle retract command was not received a limit switch should be incorporated into the design to provide for the automatic return of the baffle arm. At this time a baffle arm cycle command was also incorporated into the design which would automatically extend and retract the baffle arm once per command. Later in the program the baffle cycle command and baffle return command were eliminated due to the limited availability of spacecraft commands. The mechanical design of the baffle assembly consisted of a coiled arm that extends and retracts in a manner which is similar to the action used in a carpenter tape measure. A brushless D-C motor was initially incorporated into the design to drive the baffle arm. A monitor of baffle extension was obtained by mechanically coupling the baffle arm to a precision potentiometer which generated a D-C voltage proportional to baffle extension. Investigation into the use of a stepping motor for the baffle in/out control was initiated during the later



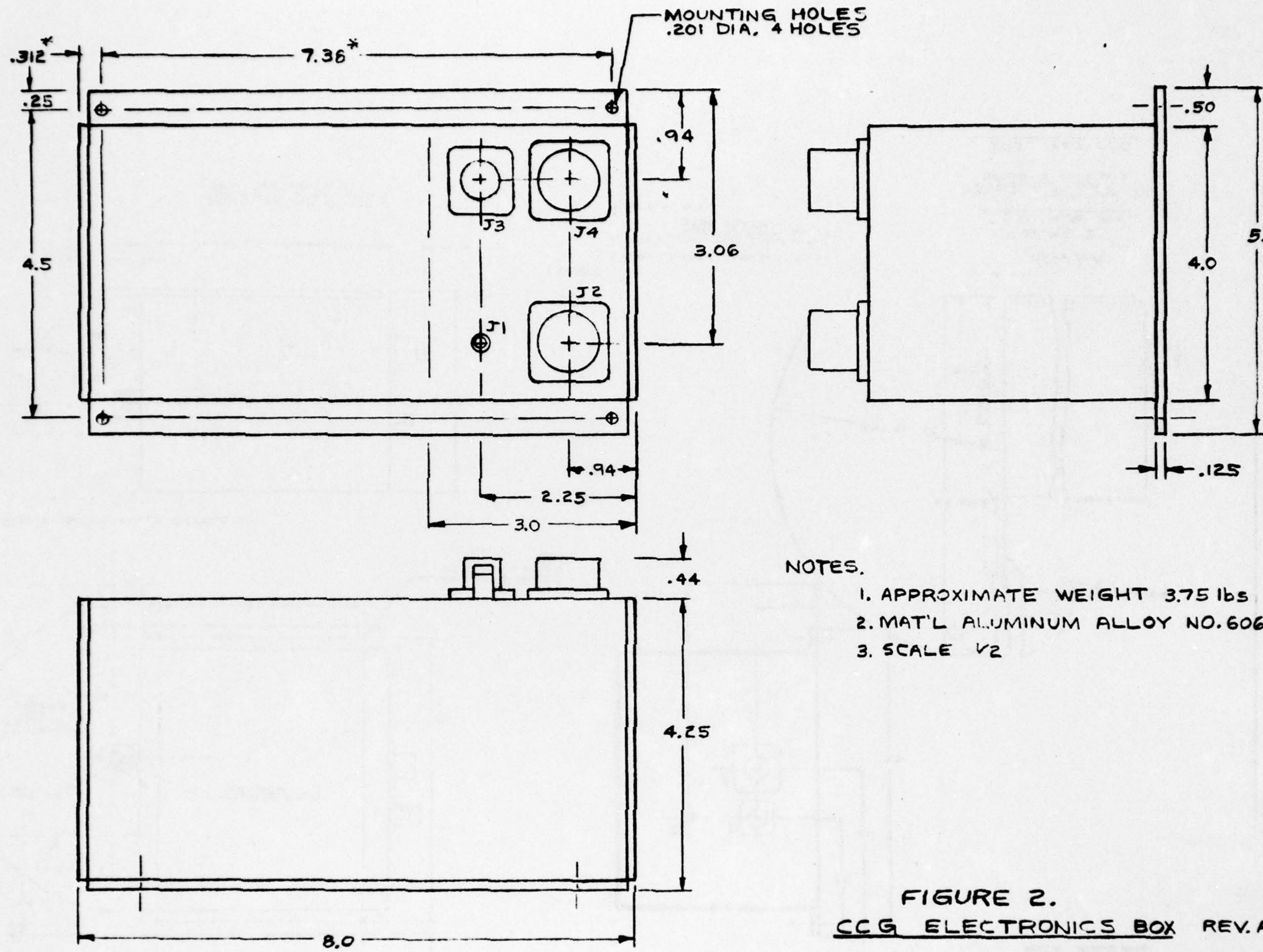
NOTES:

1. APPROXIMATE WEIGHT 9 lbs
2. MAT'L, .040 CRS CASE WITH ALUM ALLOY NO. 6061-T6 BASE PLATE.
3. SCALE = 1/2

FIGURE 1
CCS GAUGE BOX

EPSILON LABORATORY INC
4 PRESTON COURT
BEDFORD MASS 01730

AFGL 247 CCG



NOTES.

1. APPROXIMATE WEIGHT 3.75 lbs
2. MAT'L ALUMINUM ALLOY NO. 6061-T
3. SCALE 1/2

FIGURE 2.

CCG ELECTRONICS BOX REV. A

EPSILON LABORATORY INC
4 PRESTON COURT
BEDFORD MASS 01730

AFGL 247 CCG

* = REV. A

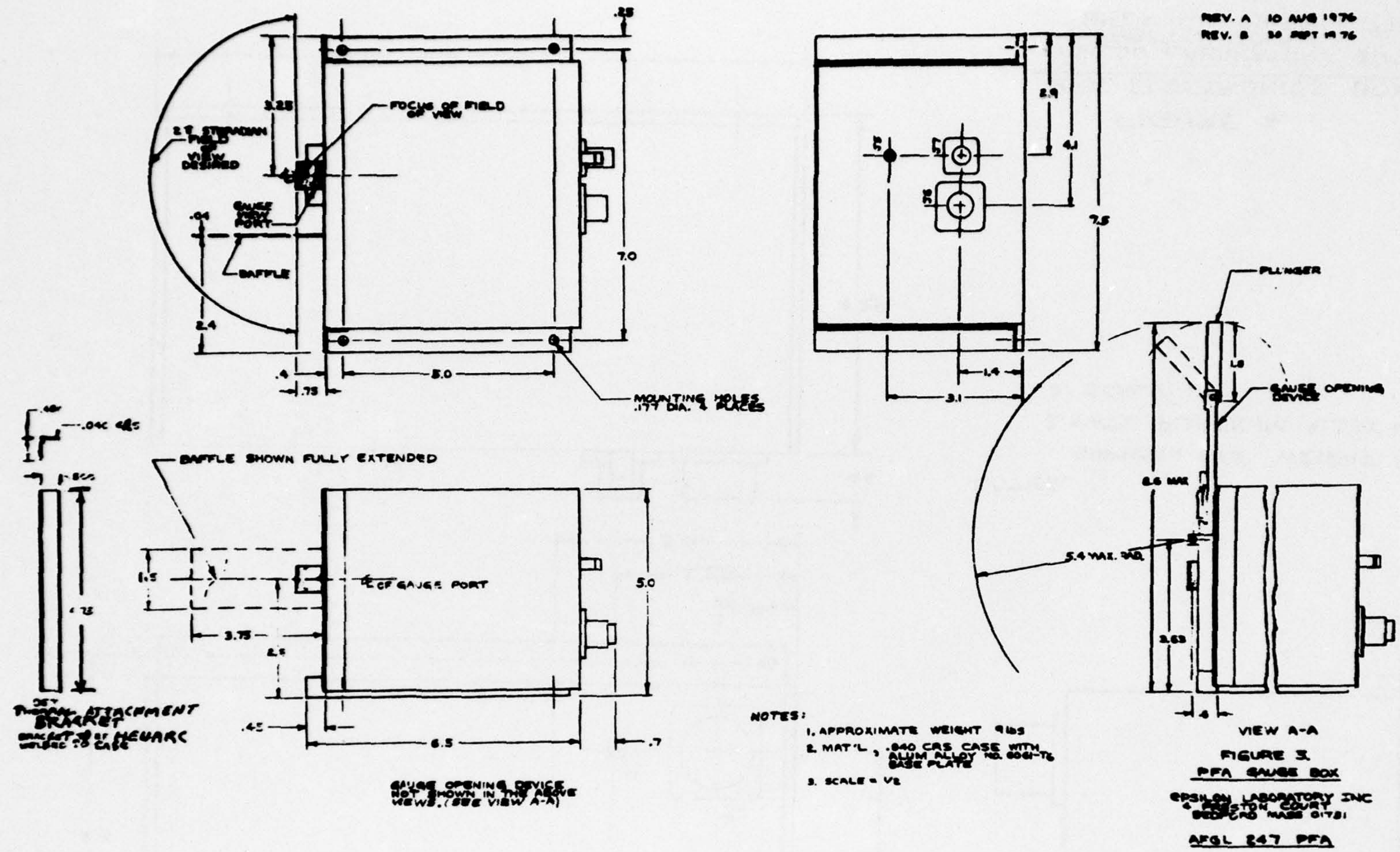
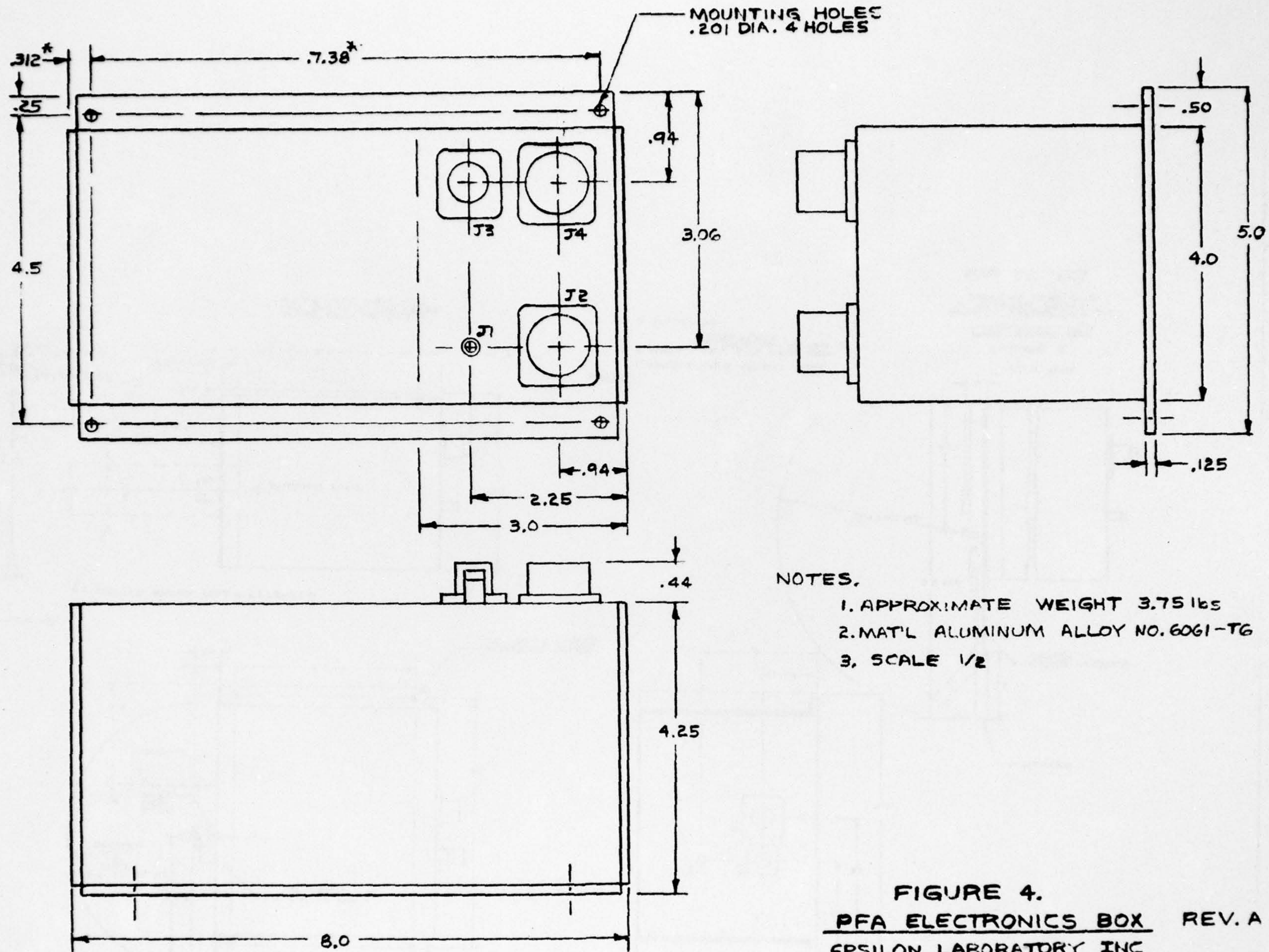


FIGURE 3.
PFA GAUGE BOX



NOTES.

1. APPROXIMATE WEIGHT 3.75 lbs
2. MAT'L ALUMINUM ALLOY NO. 6061-T6
3. SCALE 1/2

FIGURE 4.

PFA ELECTRONICS BOX REV. A

EPSILON LABORATORY INC
4 PRESTON COURT
BEDFORD MASS 01730

AFGL 247 PFA

* = REV. A

part of the design effort and was prompted both by reliability considerations and by a desire to incorporate sufficient flexibility into the design so that external commands to position the baffle to a desired position could be accommodated at a future date. Separate forward or reverse commands from the ground could thus be used to position the baffle to an arbitrary position. Inquiries were initiated to various manufacturers of stepping motors to determine if space qualified motors were available. Several manufacturers replied positively and a size 11 space qualified stepping motor was incorporated into the design of the baffle mechanism.

During the initial phase of the program an extensive investigative search was conducted with the aim of finding a suitable alternative gauge to the AFGL gauge. In considering a number of private and government sources for a gauge, Epsilon selected one manufactured by Cabot Corporation of Billerica, Mass.

The Cabot Corporation Model 529 cold cathode ionization gauge, Figure 5, modified for low input conduction, is a miniature, lightweight, low power vacuum sensor. The instrument serves to measure pressures in the range of 1×10^{-4}Torr to below 10^{-10}Torr (nitrogen) and was selected to be used in the CCG experiment. These gauges have flown on Apollo missions 12 through 15, and another version was flown successfully on the Air Force OV1-15 satellite. The Cabot gauge which has been provided by AFGL for the first system consists of the basic Model 529 modified to optimize input conductance. Figure 6 is a detail drawing of the gauge depicting the modified entrance tabulation and internal structure of the gauge. The power required to operate the sensor is less than one watt and the total weight is 2 lbs., 12 oz. A wide range (5 decade) electrometer is used to amplify and convert the output current of the gauge to an appropriate output voltage. A miniature high voltage power supply of +1800 VDC was developed to power the sensor. The PFA experiment uses the AFGL cold cathode ionization gauge which is also a miniature, low power vacuum sensor for the measurement of pressures in the range of 1×10^{-4}Torr to below 10^{-10}Torr. As is the case for the Cabot gauge, this sensor has also been successfully flown on satellites. The power required to operate the sensor is less than one watt and the total weight is approximately 2 pounds. A wide range (5 decade) electrometer is used to measure the gauge output current. A miniature high voltage power supply of +7000 VDC was developed to power this sensor.

The design effort for the magnetically shielded box to house the gauge was initiated after selection of the gauges to be used in the experiment. The primary design objective for the enclosure was to arrive at a design which achieved the best balance between the conflicting requirements of the geometric size and weight constraints for the enclosure and the permeability/saturation characteristics of materials having appropriate shielding properties.

Previously, two approaches had been considered for the shield design; the first being one in which the enclosure would be fabricated with a light weight non-magnetic material with the required shielding being provided by sheets of an appropriate magnetic material. The sheets would either be used to line the enclosure or would be used to surround the gauge at some inter-

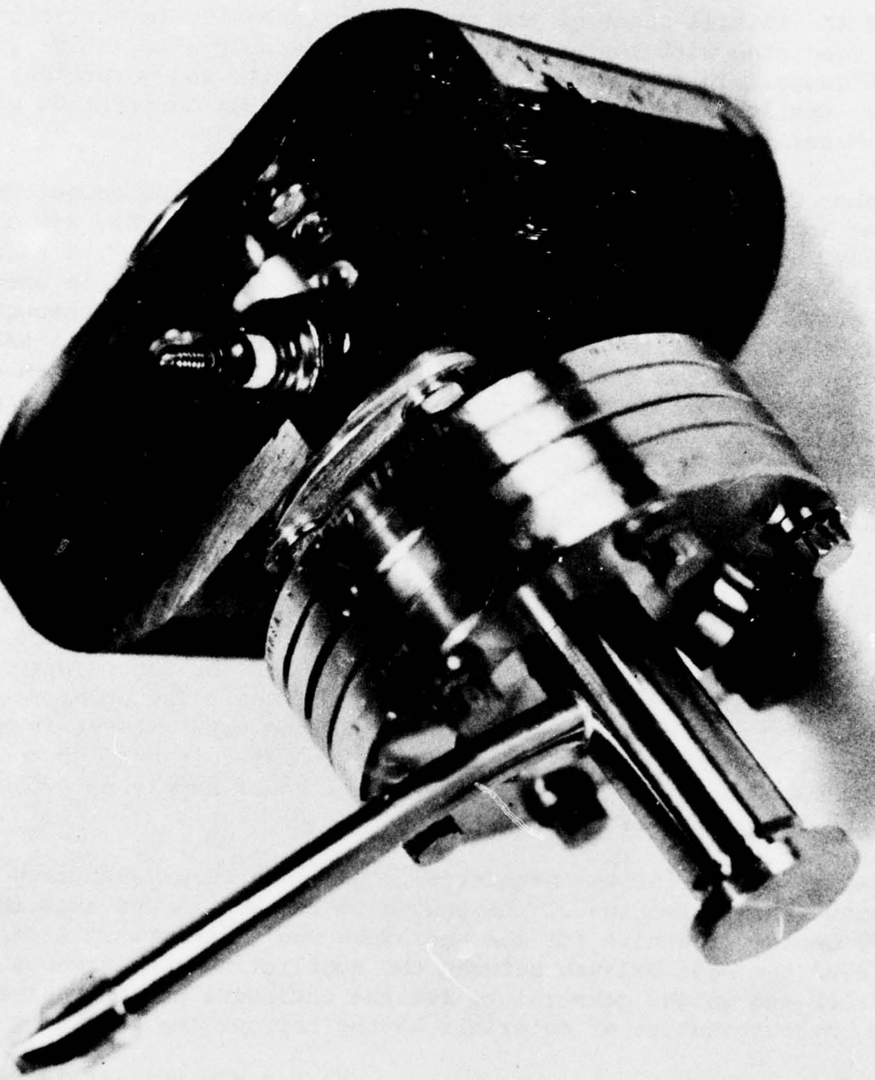


Figure 5 Cabot Gauge
Model 529

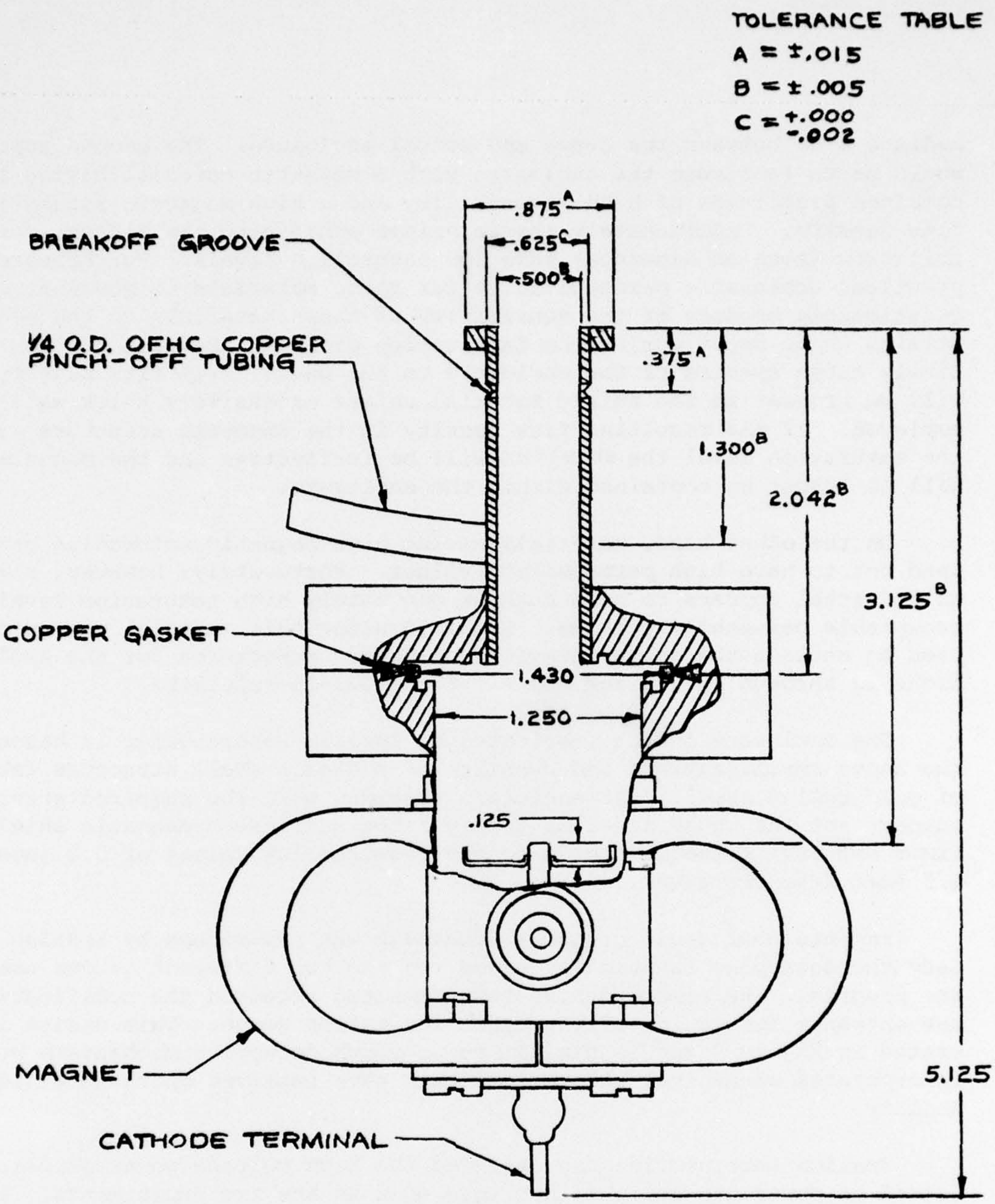


FIGURE 6.
DETAIL DRAWING OF CABOT COLD CATHODE GAUGE

mediate area between the gauge and actual enclosure. The second approach would be to fabricate the enclosure with a magnetic material having the combined properties of high permeability and a high magnetic saturation flux density. Unfortunately the materials exhibiting the highest permeabilities (such as Hipernom) have low saturation levels. Furthermore, the practical achievable permeabilities for these materials is somewhat questionable because of the sensitivity of these materials to the mechanical strains which occur during the fabrication process. Because of the relatively close spacing of the enclosure to the gauge, high flux density levels will be present in the shield material unless excessively thick walls are employed. If the resulting flux density in the magnetic structure exceeds the saturation level the shielding will be ineffective and the magnetic field will no longer be contained within the enclosure.

On the other hand, materials having high magnetic saturation properties tend not to have high permeability values. Fortunately, however, simple cold rolled steel appears to have both an adequately high saturation level and an acceptable permeability value. A shield using this material was successfully used to enclose the gauges provided by Cabot Corporation for the Apollo Missions 12 through 15 and for the Air Force OV1-15 satellite.

The enclosure design fabricated by Epsilon Laboratories is based upon the above considerations and consists of a single-shell structure fabricated of cold rolled steel. The enclosure provides both the required structural support for the gauge and also incorporates sufficient magnetic shielding to limit external magnetic fields to the required low values of 0.2 gauss at 1.5 feet from the gauge.

An interchangeable breakoff mechanism was envisioned by Epsilon to satisfy the decapping function required for the two different gauges used on the program. The common design that resulted required the modification of the entrance tubulation of the Cabot ionization gauge. This design is illustrated in Figure 7 and is similar to previous decapping mechanisms but incorporates mechanical innovations that have improved operational reliability.

Epsilon Laboratories has designed the high voltage power supplies required to power the ionization gauges used in the two experiments. Both power supply designs use a conventional DC to AC inverter circuit in which an output transformer provides moderate high AC voltage drive to a multiplier circuit thereby minimizing the possibility of voltage breakdown. The transformer output is brought up to the required gauge high voltage level using a standard diode/capacitor multiplier circuit. Because of the requirement of designing the high voltage power supply to operate with either one of two gauges currently being used in the program, two values of high voltage output were required. In the case of the AFGL gauge the required operating voltage is 7000 VDC while for the Cabot gauge the required voltage is 1800 VDC. A feedback voltage derived from a voltage tap on the output transformer is used to maintain the tap voltage at a specified level which in turn maintains a constant high voltage output.

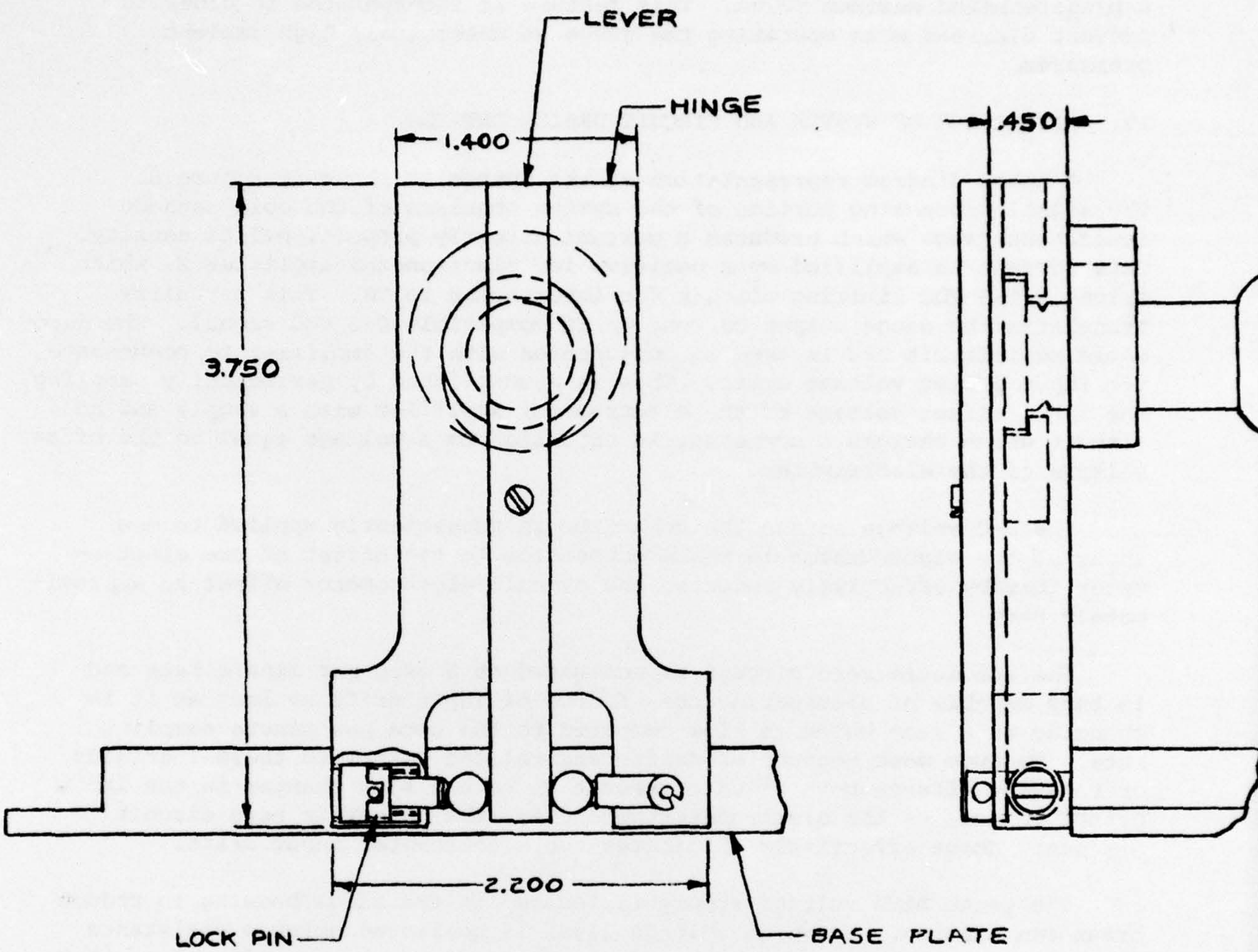


FIGURE 7.
INTERCHANGEABLE IONIZATION GAUGE
BREAKOFF MECHANISM

Constant current limiting is provided by means of a transistor limiting circuit in order to prevent the gauge current from exceeding a predetermined maximum value. This feature is incorporated in order to prevent overload when operating the gauge at excessively high ambient pressures.

IV. DISCUSSION OF SYSTEM AND CIRCUIT DESIGN DETAILS

A block diagram representation of the system is shown in Figure 8. The signal processing portion of the system consists of the cold cathode ionization gauge which produces a current directly proportional to density. This current is amplified by a positive ion electrometer amplifier Z1 which drives a 0-5 VDC limiting circuit for interfacing to TM. This circuitry translates the gauge output current to TM compatible 0-5 VDC signal. The automatic zero circuit Z10 is used in conjunction with the amplifier to compensate for input offset voltage drift. This is accomplished by periodically sampling the input offset voltage of the electrometer amplifier with a sample and hold circuit which charges a compensating capacitor to a voltage equal to the offset voltage of the electrometer.

The D-C voltage across the capacitor is subsequently applied to one input of the electrometer in phase opposition to the offset of the electrometer thereby effectively reducing the overall electrometer offset to approximately zero.

The automatic zero circuit is activated at a once per minute rate and is thus capable of eliminating the effects of input drift as long as it is changing at a rate which is slow compared to the once per minute sampling rate. Because most sources of drifts are related either to thermal effects or to aging effects both of which result in rather slow changes in the input offset voltage of the electrometer amplifier, the automatic zero circuit discussed above effectively eliminates the electrometer input drift.

The gauge high voltage supply is located in the gauge housing to reduce breakdown hazards. The high voltage level is monitored using a resistance divider and an associated zener diode limiter circuit to provide a 0 to +5 V output which is proportional to the high voltage output. The high voltage power supply is a conventional inverter circuit which, as discussed above, utilizes a transformer to provide a moderately high A-C voltage drive to a voltage multiplier circuit which provides the final required voltage. In order to provide protection against possible excessive gauge currents at the high atmospheric pressures the supply provides for constant current limiting. The threshold point of current limiting is just above the current corresponding to the highest atmospheric pressure of interest so that the current limit features will not influence gauge operation within the normal range of ambient pressure.

Temperature sensors Z2 and Z7 are National Semiconductor LX5600 temperature transducers and provide an output directly proportional to gauge and electronic package temperature. They are limited to a 0-5 VDC range in a buffer amplifier before being provided to the TM. A gauge open monitor circuit, Z3, provides a confidence check that the pyrotechnic devices have

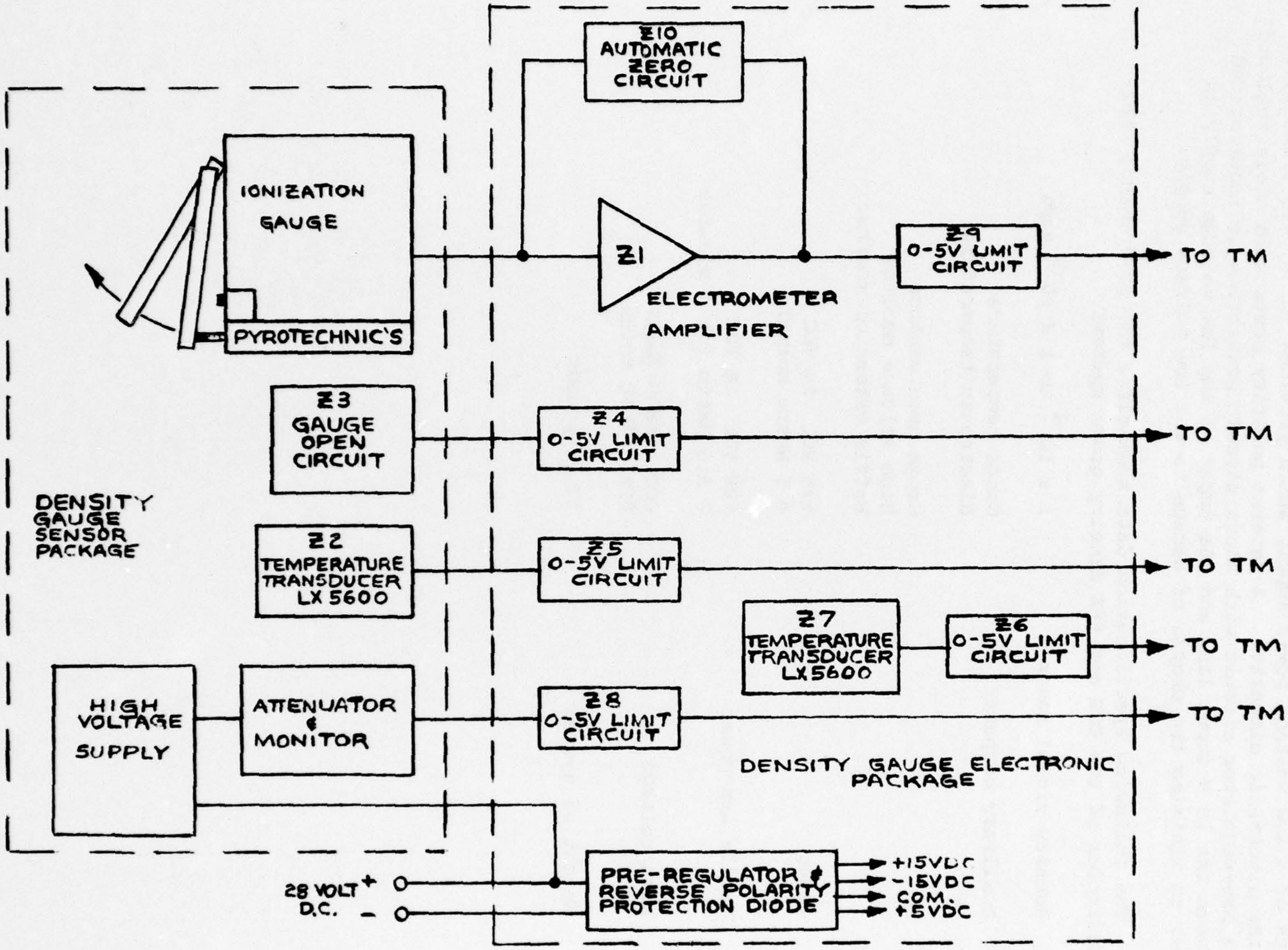


FIGURE 8
DENSITY GAUGE SYSTEM BLOCK DIAGRAM

fired and exposed the gauge properly. The remainder of the system consists of a low voltage power supply which provides +15 V, -15 V and +5 V to the electronic circuitry. A reverse polarity protection diode followed by a pre-regulator circuit with short circuit protection is incorporated between the 28 V input line and the input of the low voltage supply in order to minimize the chance of damage to the low voltage supply.

The following specification data summarizes the performance characteristics of the CCG and PFA density gauge systems.

Density signal range	1×10^{-4} to 1×10^{-9} amps
Auxiliary outputs	Gauge temperature Electronic temperature Gauge open monitor High voltage monitor Baffle extension monitor
Power	+28 VDC ±4 VDC @ 5 Watts normal
Baffle arm power	+28 VDC ±4 VDC @ 5.6 Watts for 3 minutes
High voltage	CCG +1800 Volts PFA +7000 Volts
Weight of system	12.75 pounds